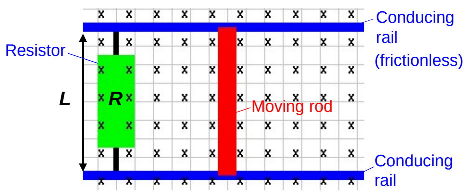
Motional emf

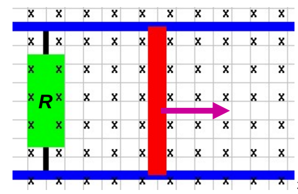
A moving rod can act like a battery if we connect it up in a circuit like the following:



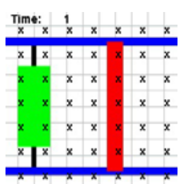
Direction of the induced current?

If the rod (in red) is moved to the right, will there be an induced current? If so, in what direction is it?

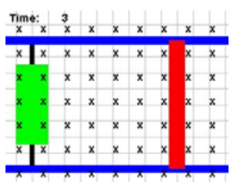
1. Clockwise
2. Counterclockwise
3. There is no induced current



Apply the pictorial method



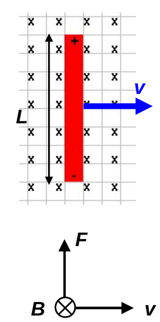
Before



After

The simulation draws the Before and After pictures for us. To oppose the change, the loop needs to create field lines out of the page, requiring a counterclockwise induced current.

Motional emf – figuring out the sign

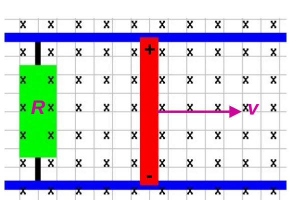


We can think of the rod as acting like a battery.

Imagine that the positive charges in the rod are moving to the right at speed ***v*** in a magnetic field ***B*** as shown at left. By applying RHR-1, a magnetic force is produced that will push the positive charges up. Similarly, the negative charges in the rod are pushed down. The resultant polarization of charges in the rod leads to an emf!

Motional emf – figuring out the sign

Notice that the sign we figured for the motional emf by using RHR-1 is consistent with the current we figured out earlier by using Lenz's law!



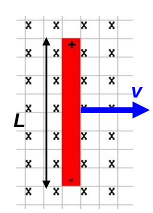
Motional emf – the magnitude

Motional emf is the voltage induced across a conductor moving through a magnetic field. If a metal rod of length *L* moves at velocity ***v*** through a magnetic field ***B***, the motional emf is:

$$\varepsilon = -vLB$$

Notice that the velocity, field, and length are assumed to be mutually perpendicular in this equation. We can derive this equation from Faraday's Law.

If the circuit is closed, the current in the circuit is the motional emf divided by the total resistance of the circuit.



Acting like a battery

The rod is initially at rest, but is then subject to a constant force ***F*** directed right. Neglect friction between the rod and the rails. What happens?

1. The rod experiences a constant acceleration, and the speed increases at a constant rate
2. The changing flux gives rise to another force in the same direction as ***F*** that accelerates the rod even faster than ***F*** would by itself.
3. The changing flux gives rise to another force opposite in direction to ***F*** that causes the rod to reach a terminal (constant) velocity
4. The changing flux gives rise to another force opposite in direction to ***F*** that causes the rod to come to rest

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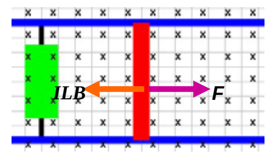
Acting like a battery



Initially, the rod accelerates to the right due to the applied force ***F***. But the faster the rod goes, the larger the current is induced in the loop (defined by rod-rail-resistor-rail). (Why?) In turn, the induced current produces a magnetic force ***ILB*** that opposes ***F*** and slows the rod down. In the end, the magnitude of two forces are the same (so there is no net force) and the rod moves at a steady velocity, which is determined by: $|\varepsilon| = vLB = IR$.

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Back emf

In a closed circuit that is driven by a voltage source (such as a battery or the mains supply), the motional emf, if exists, constitutes the back emf.

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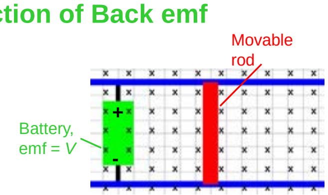
Direction of Back emf

A movable rod, two long frictionless rails and a battery with emf *V* completes a circuit as shown at right. What is the direction of the back emf?



(1) Same direction as the emf of the battery

(2) Opposite to that of the battery.

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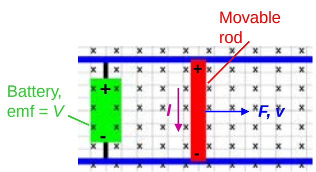
Direction of Back emf



The battery drives a downward current in the rod. By using the RHR-1, the magnetic force would be produced that points at right. This causes the rod to move in the same direction. In turn, this right-ward motion leads to a motional emf. By using the RHR-1, we can figure that the direction of the motional emf is opposite to that of the battery.

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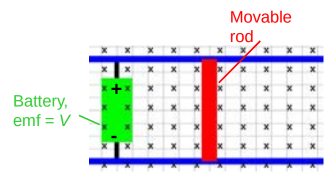
Steady state

A movable rod, two long frictionless rails and a battery with emf *V* completes a circuit as shown below. Find the speed of the rod in the steady state if the friction between the rod and the rails can be ignored.



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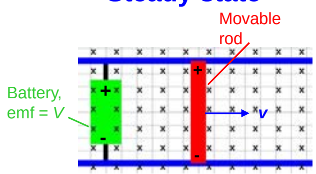
Steady state



Before steady state V > ε, the current in the circuit produces a magnetic force that accelerates the rod to the right (so the speed of the rod increases with time). But when the back emf (*vLB*) reaches the value equal to the emf of the battery, the current and hence the magnetic force becomes zero and the rod moves at a steady speed. At the steady state, we have:

$|\varepsilon| = V \Rightarrow vLB = V.$

This gives, $v = V / (LB)$.

Eddy currents

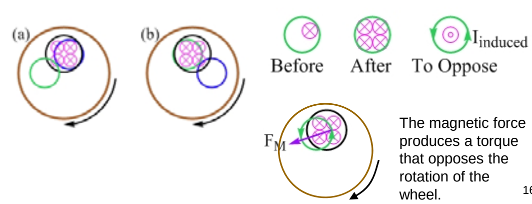
Eddy currents

An eddy current is a swirling current set up in a conductor in response to a changing magnetic field. By Lenz's law, the swirling current sets up a magnetic field opposing the change. In a conductor, electrons swirl in a plane perpendicular to the magnetic field.

Eddy currents cause energy to be lost. More accurately, eddy currents transform more useful forms of energy, such as kinetic energy, into heat, which is generally much less useful. In many applications the loss of useful energy is not particularly desirable, but there are some practical applications such as train brakes.

Eddy current application: train brakes

During braking, the metal wheels are exposed to a magnetic field from an electromagnet, generating eddy currents in the wheels. The magnetic interaction between the applied field and the eddy currents acts to slow the wheels down. The faster the wheels are spinning, the stronger the effect, meaning that as the train slows the braking force is reduced, producing a smooth stopping motion.



Eddy current question

To stop (or slow down) the train, an electromagnet is turned on, passing a magnetic field through sections of the train's wheels. The eddy currents set up in the wheels act to slow the train down. What would happen if the direction of the magnetic field was reversed?

1. The train would still slow down.
2. The train would speed up.

Eddy current question

If the field goes the other way, the eddy currents also reverse direction. Reversing both the field and the current gives a force ($F = ILB$) in the same direction – the train still slows down.